

Interferometric Characterization of Keck Segment Edge Errors

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SPIE Astronomical Telescopes & Instrumentation

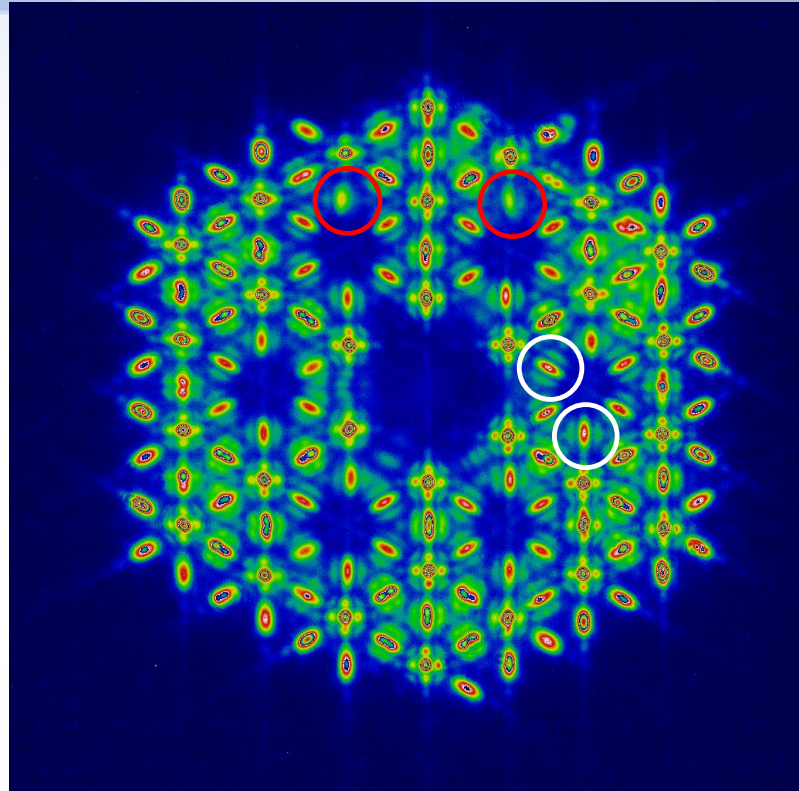
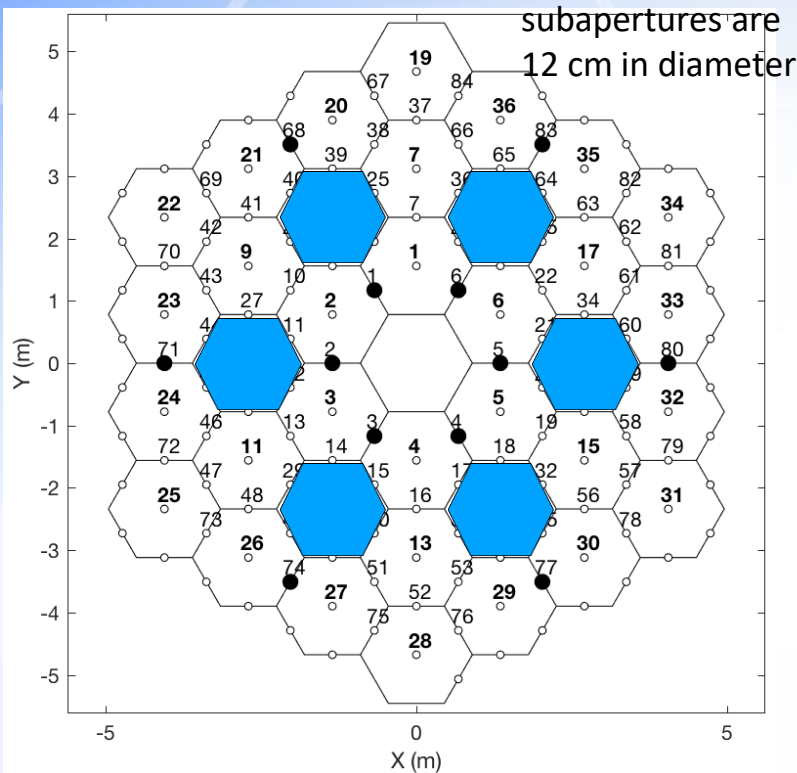
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Outline

- Introduction to Problem
- Description of Measurements
- Data Reduction and Analysis
- Results
- Conclusions and Future Work

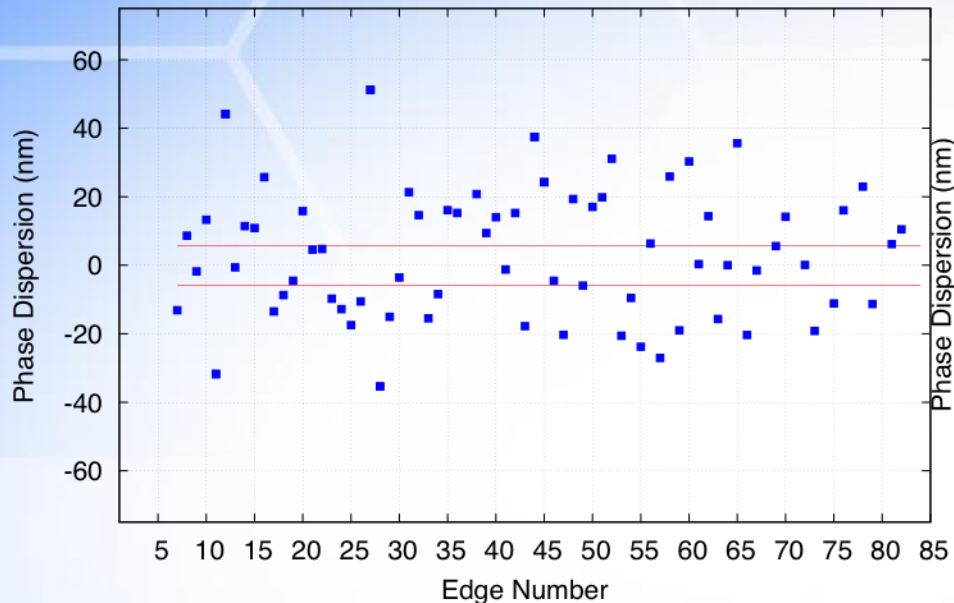
On-Sky Observations: Scattered Light From Segment Edges



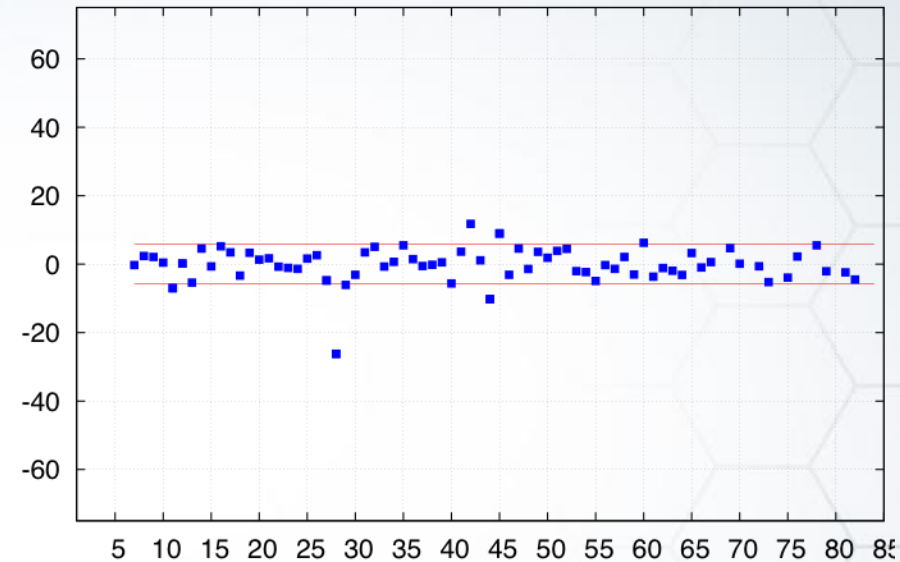
- Photometry from a segment edge over a 6 cm semi-circle can be measured using the above subaperture mask and tilting segments out of the stack
- 25% of the 72 Keck segments have edges with a significant reduction ($> 20\%$) in intensity within ± 3.5 arcseconds.
- Edges with low subimage intensity correlate to large chromatic phase dispersions.

On-Sky Observations At Keck: Chromatic Phasing Effects

True Phase Dispersion: $(p(618) + p(651) - p(852) - p(891))/2$



Pseudo Phase Dispersion: $(p(618) - p(651) + p(852) - p(891))/2$

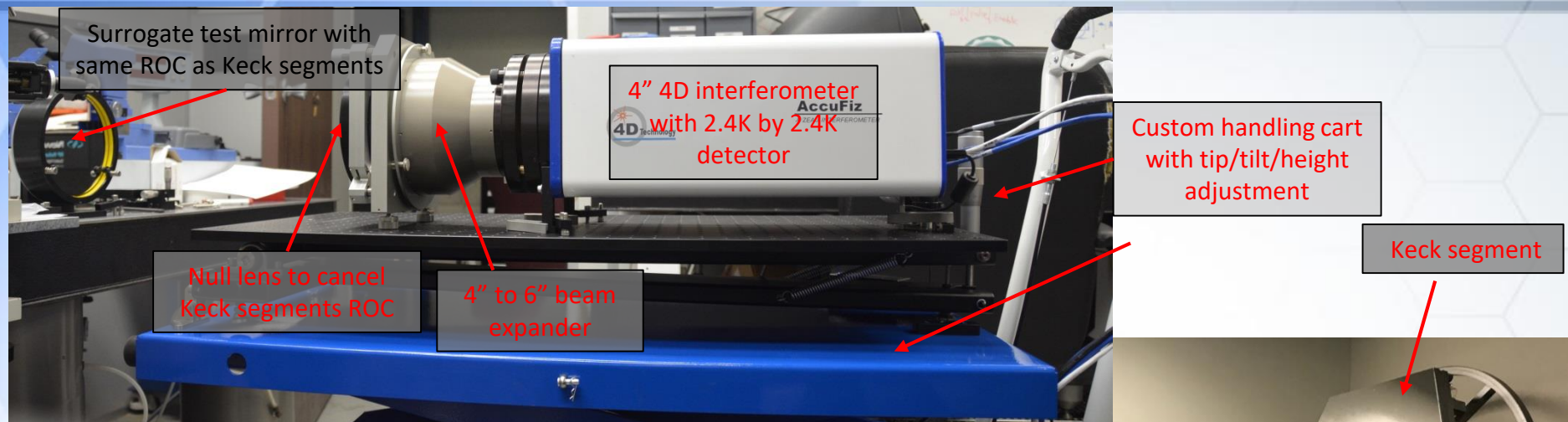


- The Keck Phasing Camera System measures the phase step between segments over 120 mm diameter subapertures
- These phase errors should be independent of wavelength, but are not.
- Phase dispersion is defined as the difference between the edge height measured at ~600 nm and at ~900 nm. RMS phase dispersion is 20 nm.
- Phase dispersion uncertainties [determined from a different linear combination of edge heights [right]] are 5 nm.

On-Sky Observations Summary

- Phase dispersion and scattered light have been measured at the center of the segment edges and at ± 200 mm along the segment edges
- When the phasing subapertures are moved well into a single segment both effects disappear
- The effects are tied to individual segments
 - Remain after segment re-coating
 - Independent of which telescope the segment is installed in.
- The following have been ruled out as causes
 - Segment reflectivity
 - Segment surface roughness
 - Low spatial frequency errors over the 60mm radius of the phasing subapertures

TMT Interferometric Test Configuration

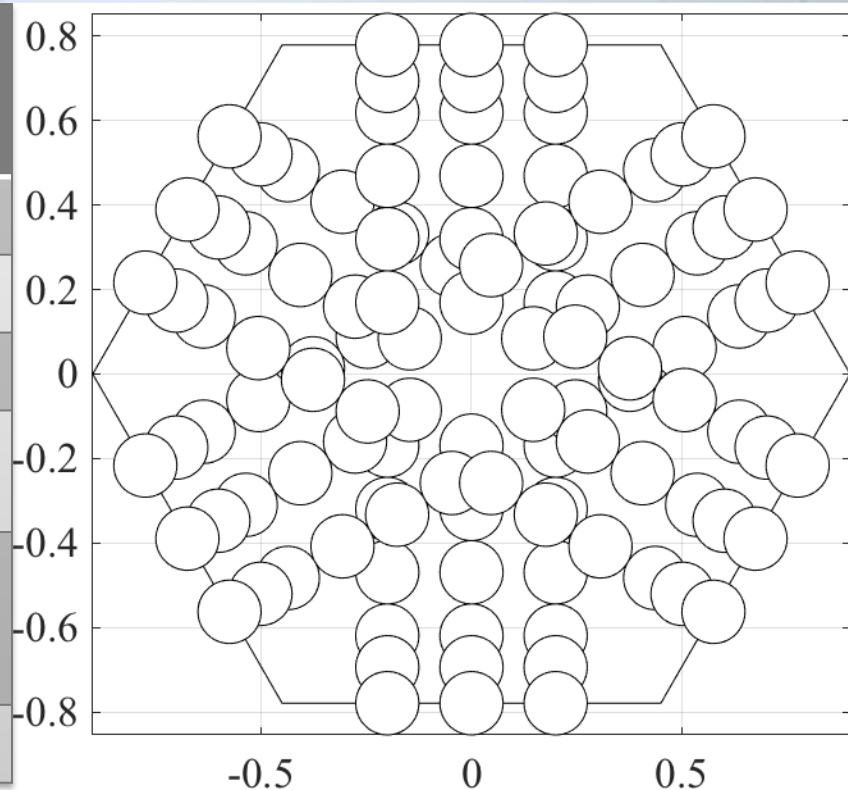


- AccuFiz H100S Fizeau Interferometer 6MPixel
- Phase measurements made over a 6" diameter
- 0.13 mm/pixel sampling
- Data collected in "Low Resolution mode"
- 32 frame averages
- RMS measurement noise: < 1.2 nm surface



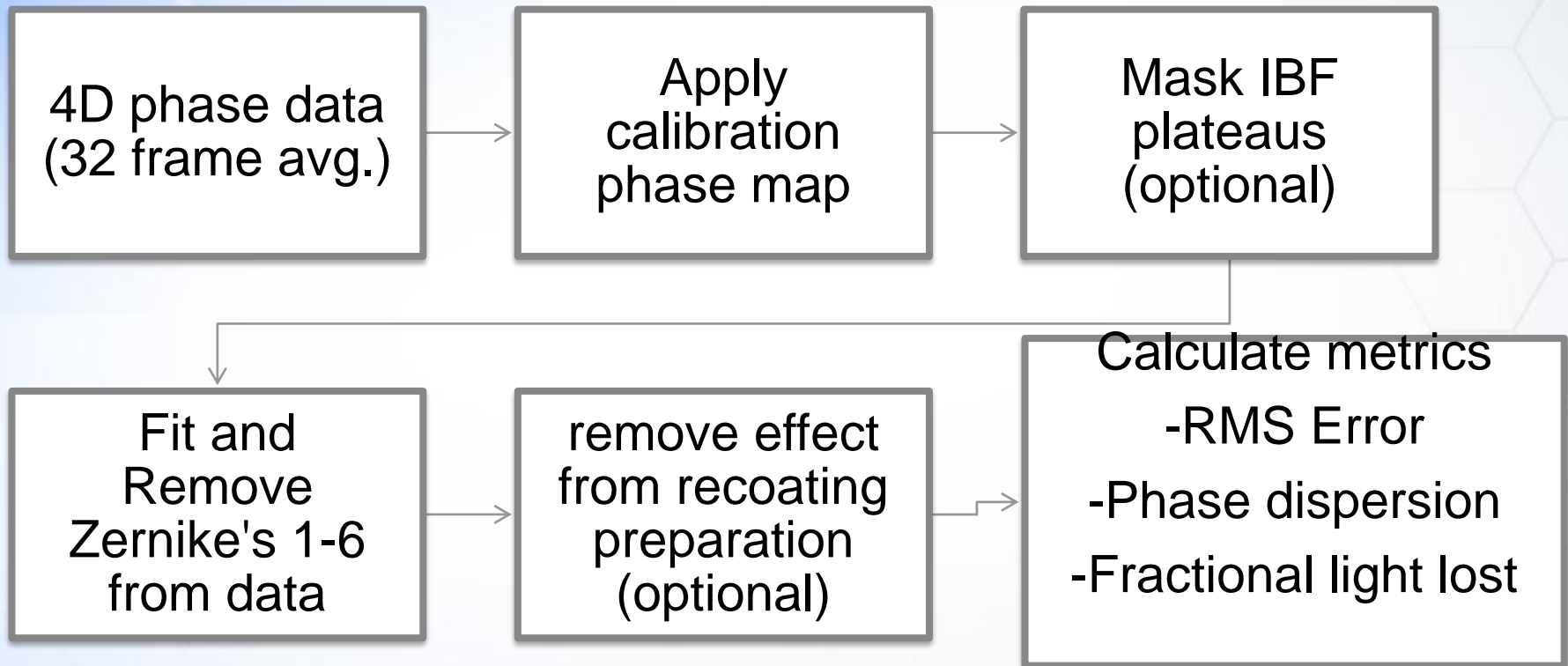
Summary of Data Collected

Segment (S/N)	Number of locations measured	Comments
38	84	High priority segment
21	36	High priority segment
56	72	High priority segment
88	36	Freshly re-coated segment
51	108	Segment just removed from telescope
Total	336	



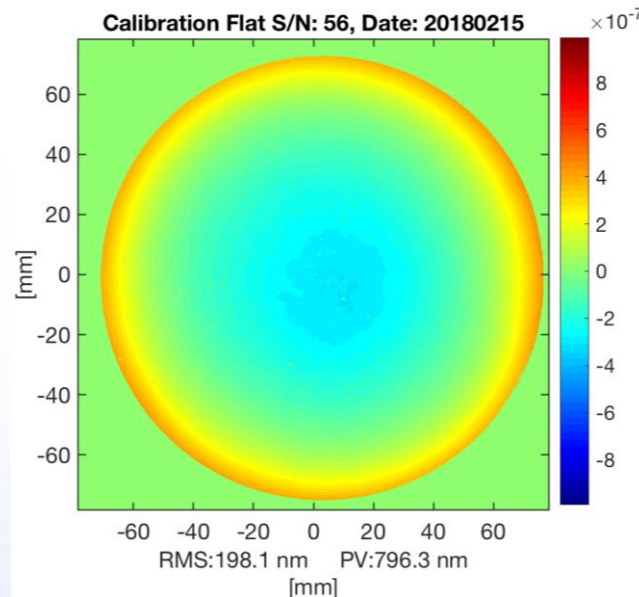
- $X = 0, Y = 0$ (on center of segment edge) measured for all segments
- 3 segments with observed on-sky phase dispersions and fraction light loss were measured
- 2 additional segments were measured, due to artifacts on the 3 high priority segments from recoating preparation

Data Reduction and Analysis



Calibration phase map

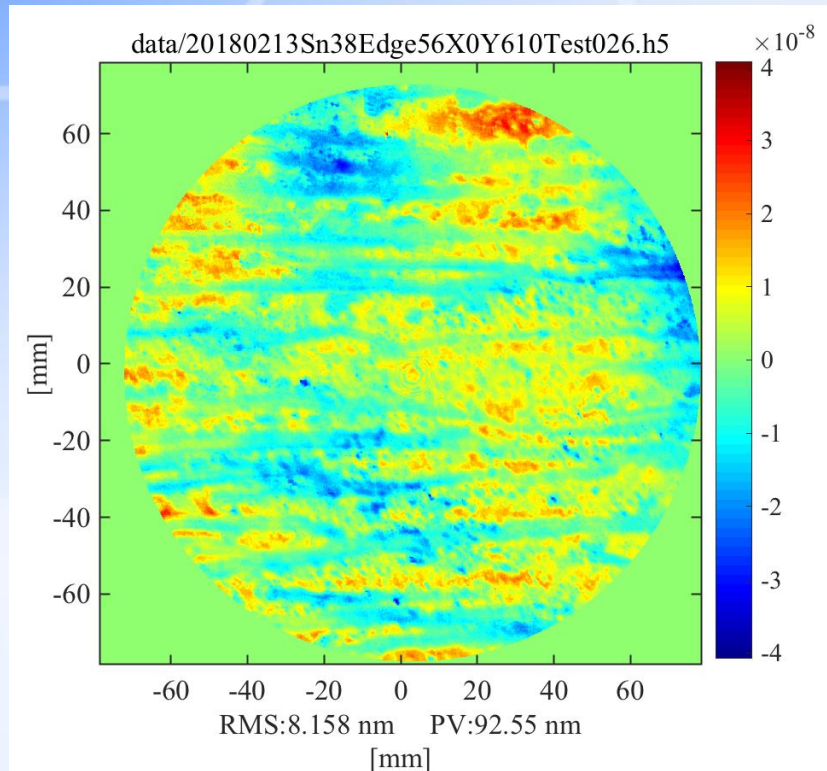
- In order to calibrate the interferometer and test optics measurements were averaged for each segment over all X locations and for Y = 310 and 460mm for each segment.



Ion Beam Figuring (IBF) Plateaus

- During IBF the segments were supported by “J-Hooks”, which resulted in areas where IBF was not performed and IBF plateaus
- Initially IBF was performed with supports that were:
 - 60 by 30 mm centered each 3 segment edges
- As a result of the measured we made at Keck and additional investigation into documents from 25 years ago we rediscovered that the supports were reconfigured
 - The supports were moved to the opposite 3 segment edges
 - Two supports per segment edge
 - Supports are centered at $x \sim \pm 275\text{mm}$ along a segment edge
 - This change occurred after the first 3 segments were IBFed

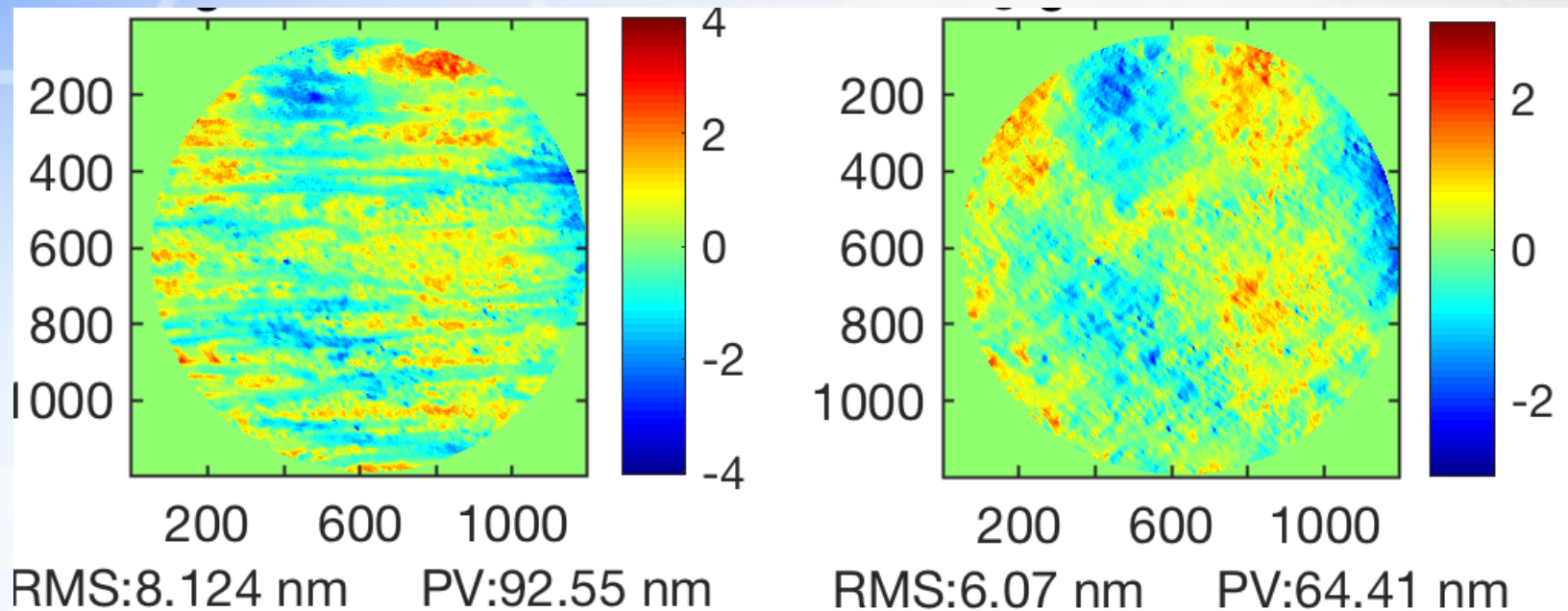
Segment Recoating Preparation Effect



- Pattern rotates with segment edge orientation
- Pattern is parallel to edge vertices 1 and 6
- The pattern is a result of the first step in preparation for segment recoating
 - Washing with XXX, which partially dissolved the Al coating
 - This was performed on all 3 of our high priority segments

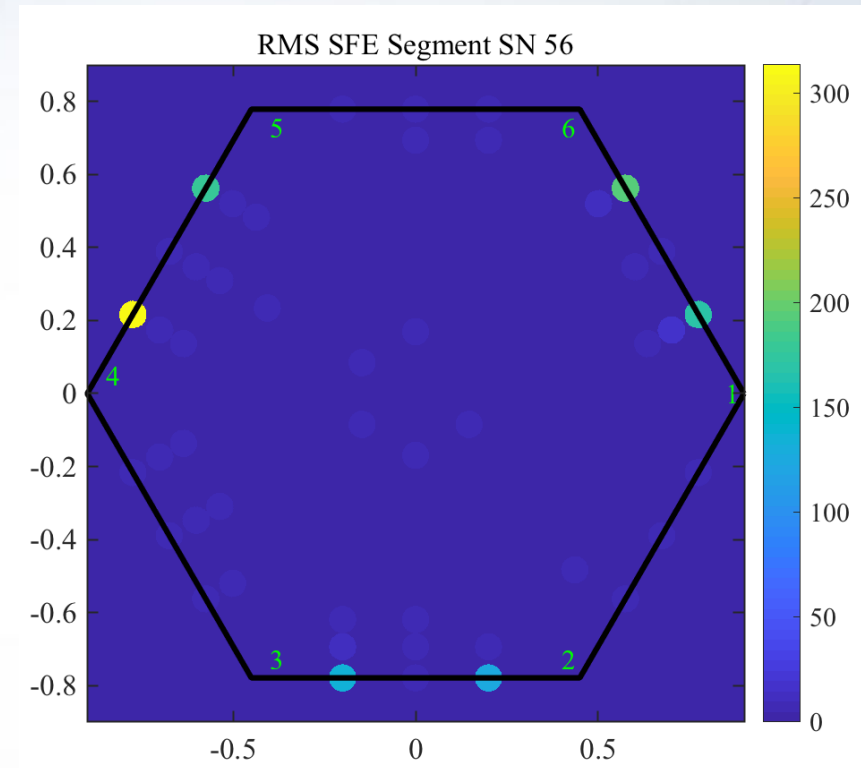
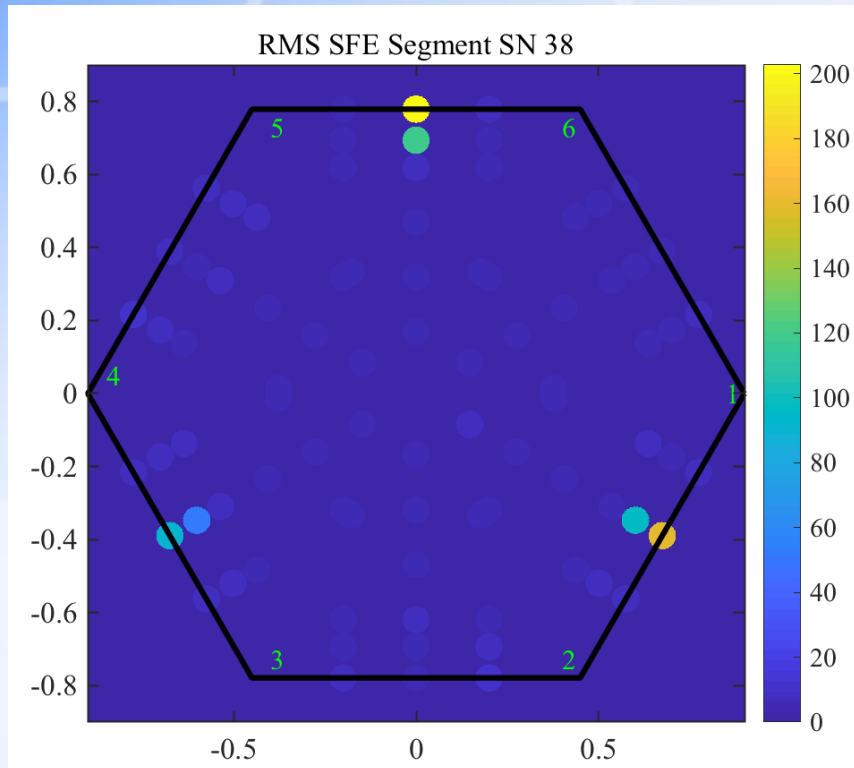
- This error looks similar to the effect we were expecting to see, but is unrelated
- As a result we also took measurements on two additional segments which had not undergone this process

Removal of the Recoating Preparation Effect



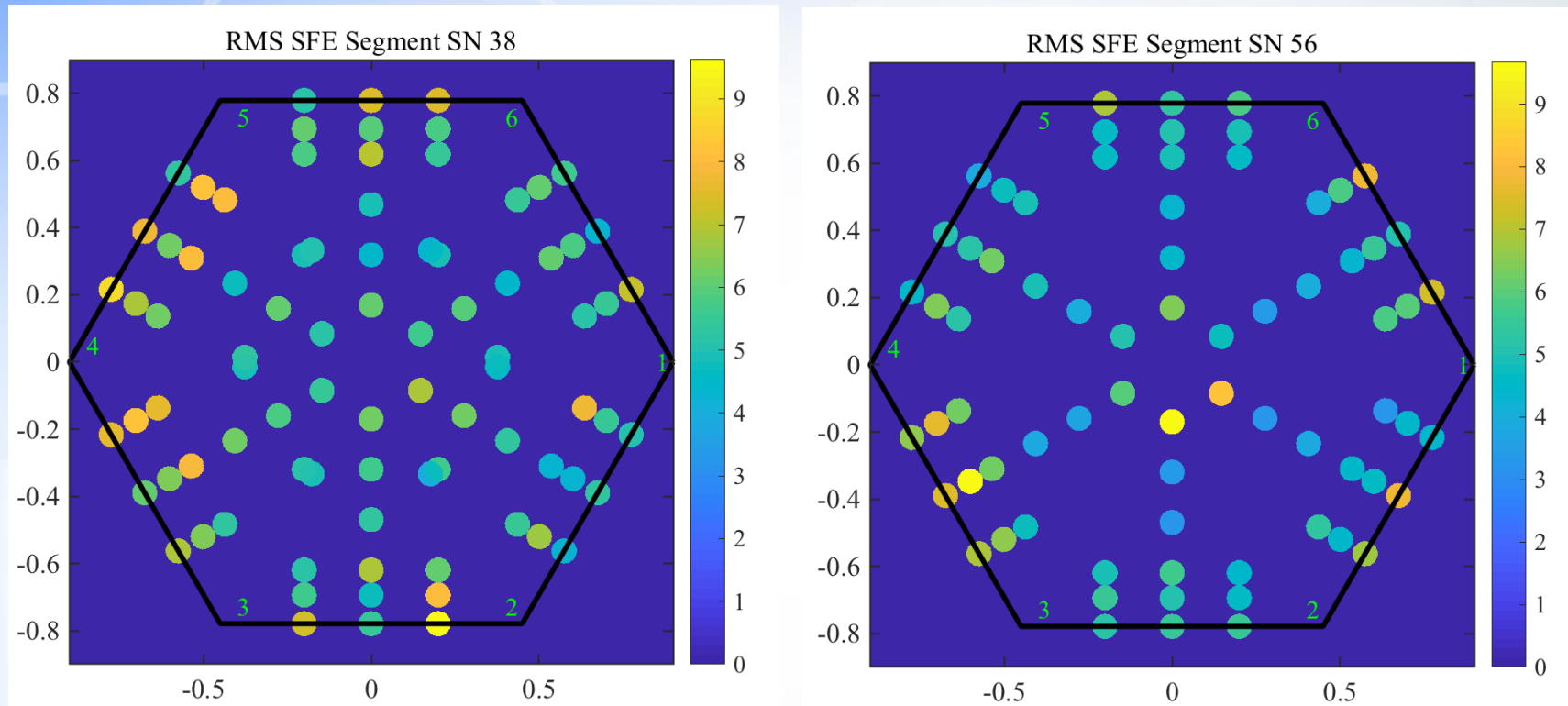
- Using a Fourier filter we were able to effectively remove the
- All data presented has this effect removed (if needed)

Example Segment RMS Errors (IBF Plateaus Not Masked)



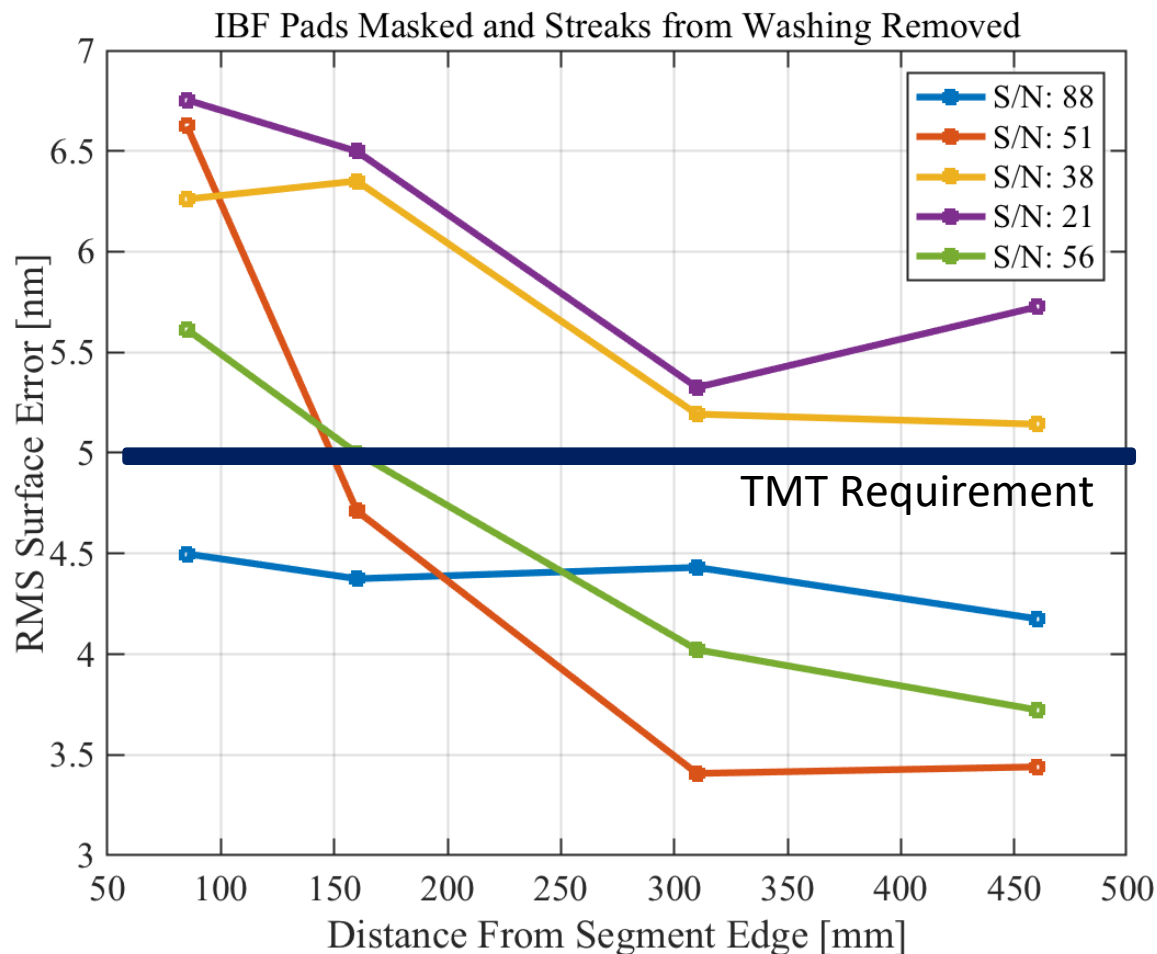
- RMS errors over measured subapertures dominated by IBF plateaus
- Each circle is centered on the measurement location, but has $\frac{1}{2}$ the diameter of the measured area

Example Segment RMS Errors (IBF Plateaus Masked)



- ◆ RMS surface errors between 3 and 10 nm
- ◆ A general trend that errors are larger near the outer portion of the segments

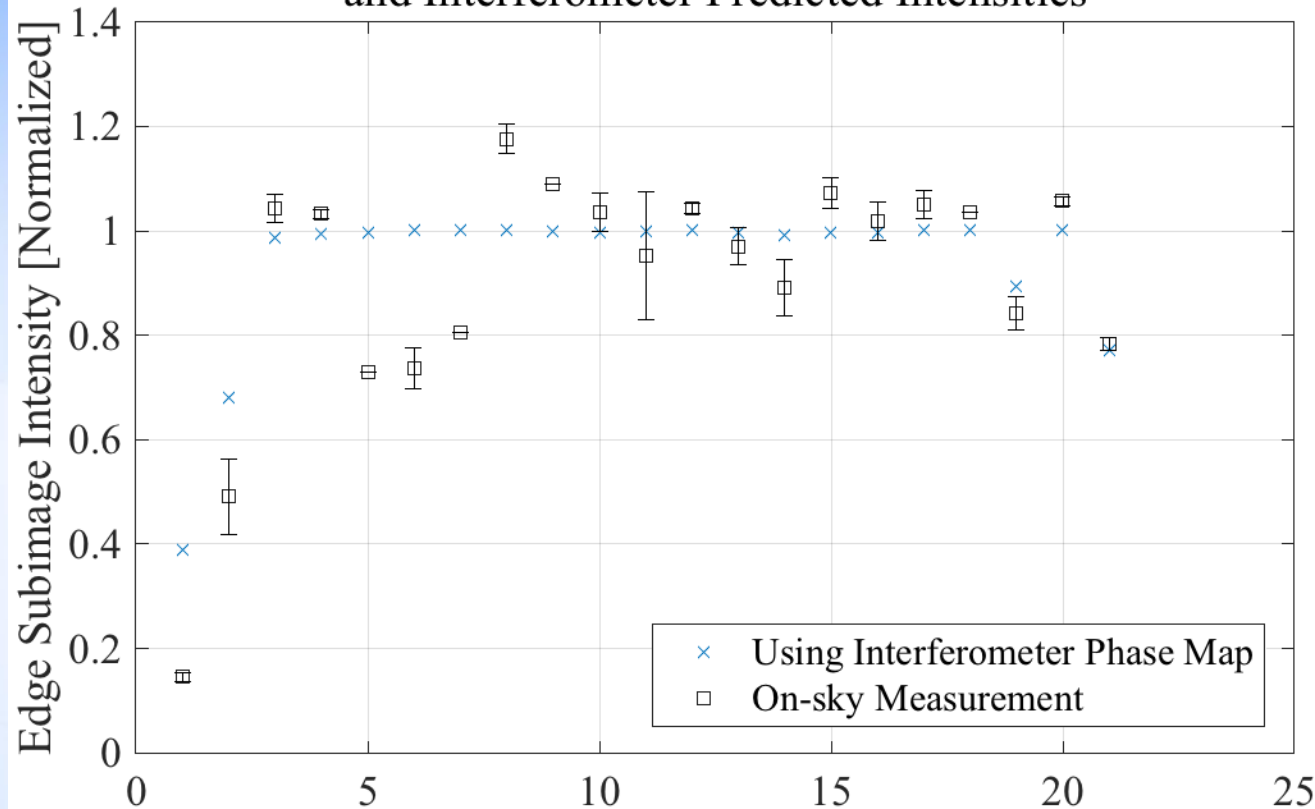
Summary of Segment Surface Errors



- There is a general increase in RMS surface error that starts to occur at $\sim 0.2\text{m}$ from the edge of the segment
- The TMT requirement is $\sim 5\text{ nm}$ RMS SFE for spatial periods $< 50\text{mm}$

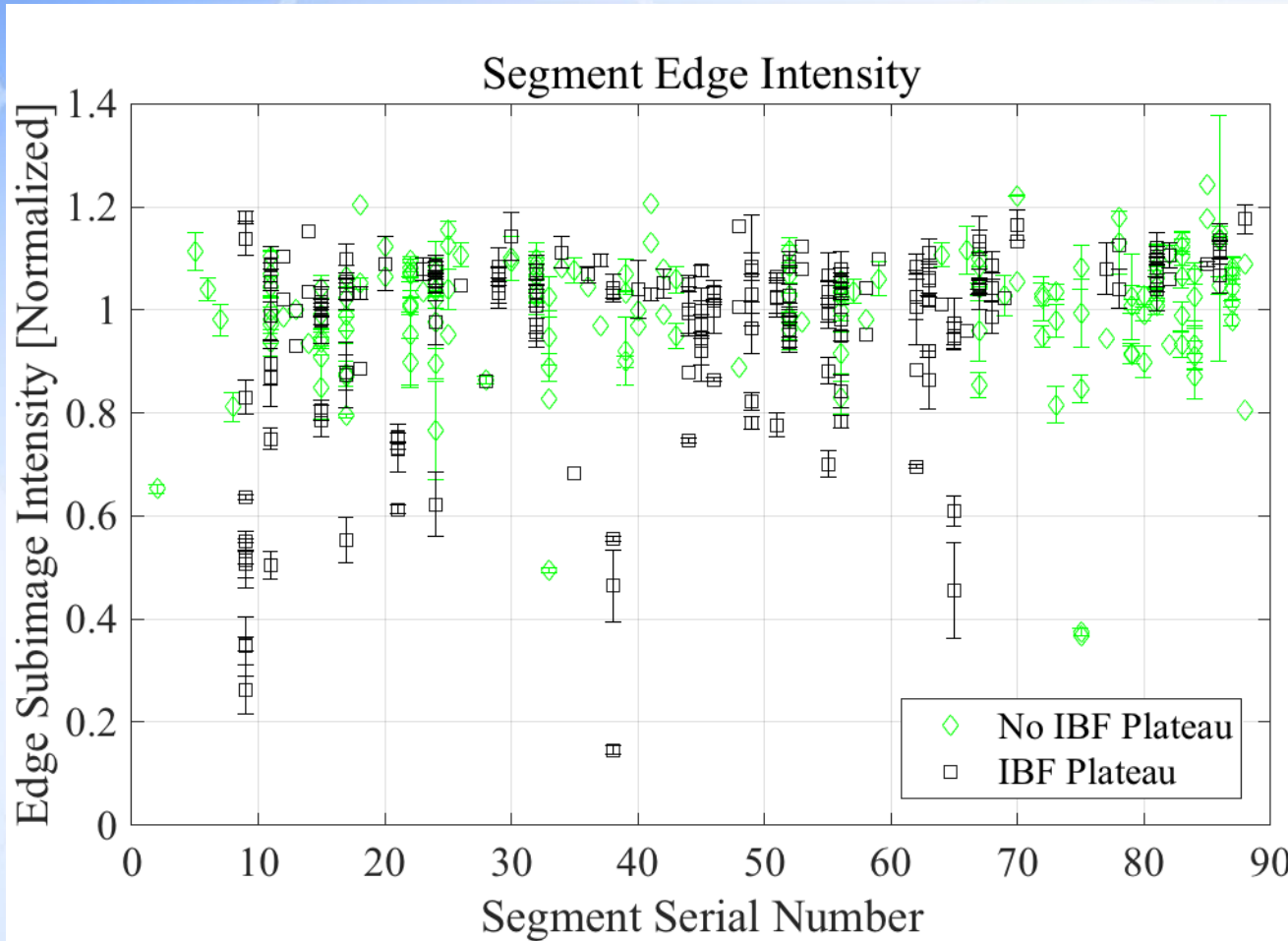
Scattered Light

Comparison of On-Sky Measured
and Interferometer Predicted Intensities



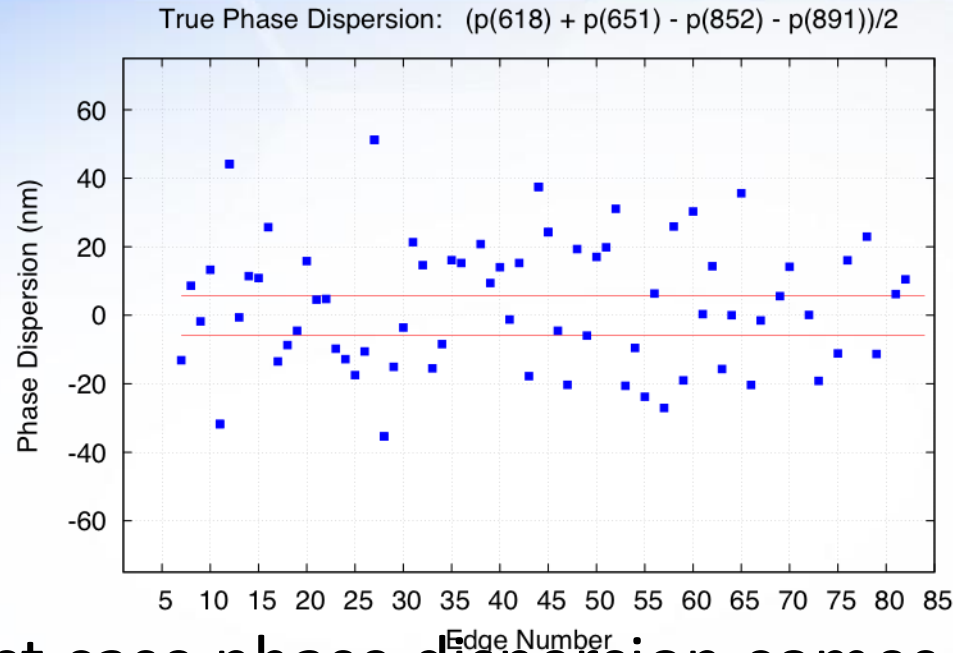
- General agreement
- IBF plateaus scatter significant light

On-Sky Scattered Light is Dominated by Edges With IBF Plateaus



- The worst scattered light comes from IBF plateaus
- They IBF plateaus do not explain all of the on-sky observed scattered light

Phase Dispersion



- ◆ The worst case phase dispersion comes from IBF plateaus
- ◆ They IBF plateaus do not explain all of the phase dispersion

Summary and Future Work

- ◆ The on-sky measurements of phase dispersion and scattered light have multiple contributors
- ◆ The largest errors are caused by the IBF plateaus
 - ◇ These plateaus have caused significant confusion
 - ◆ The location of the IBF plateaus at $\pm 225\text{mm}$ was unknown until these measurements were made
 - ◆ The spatial size of the plateaus at $X=0$ are larger than initially thought
- ◆ There is a 2nd effect
 - ◇ See Gary Chanan's talk for an explanation of the remaining phase dispersion and scattered light errors

Summary and Future Work

- ◆ There is an unexpected increase in RMS surface error with in ~ 0.2 meters of the segment edges
- ◆ These measurements have helped us to understand the effects at Keck and reduce risk for TMT:
 - ◇ The phasing issues are better, but not completely understood yet.
 - ◇ Shown that segments which met the TMT specifications are achievable

Acknowledgements

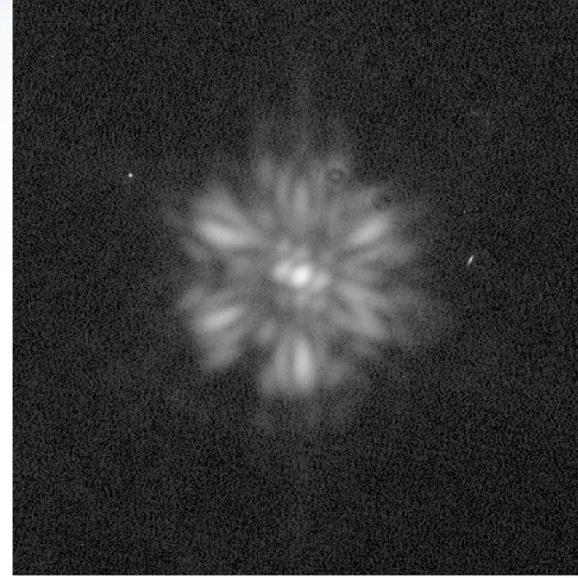
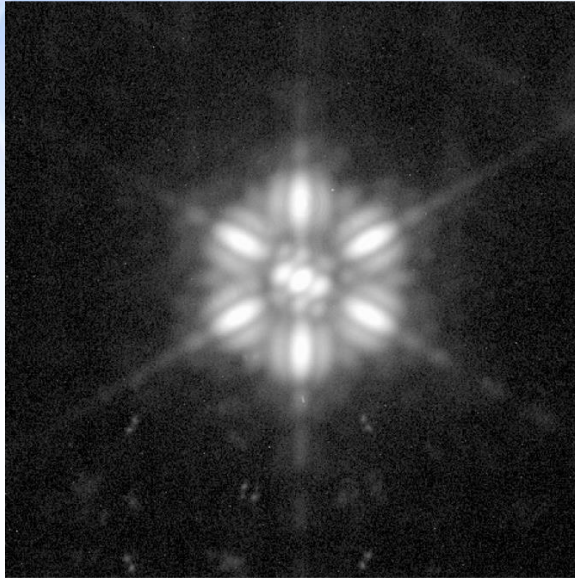
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Backups

Segment Edge Artifacts (From a working telescope)

- ◆ Keck segments appear to suffer from small but significant surface artifacts near the edges (60-100mm) that:
 - ◇ Place limits on phasing accuracy by creating a chromatic effects
 - ◇ Directly impact image quality due to light diffracted at angles larger than ± 3.5 arcseconds from the edges.
- ◆ These effects are likely caused by IBF residuals with a spatial period of 1-3 cm and 10-20 nm amplitude.
 - ◇ Measurements of the Keck segments with an interferometer have recently been executed by TMT and we are in the process of analyzing the data

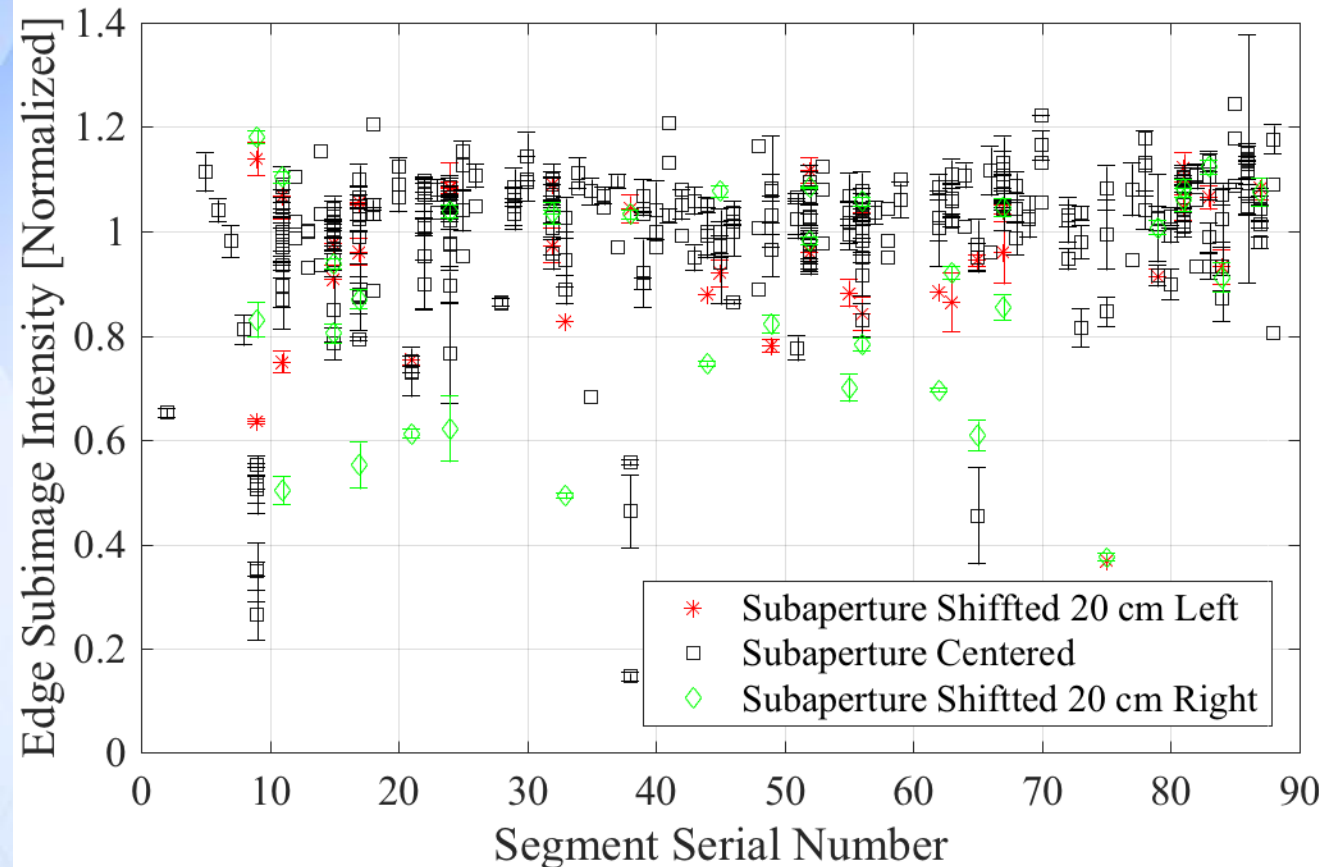
Scattered Light From Edges Single Segment



- Images are diffraction patterns formed by light from single segments passing through the phasing camera optics with the phasing mask
- On the left a good segment and on the right one of the worst segments (SP14/SN09).

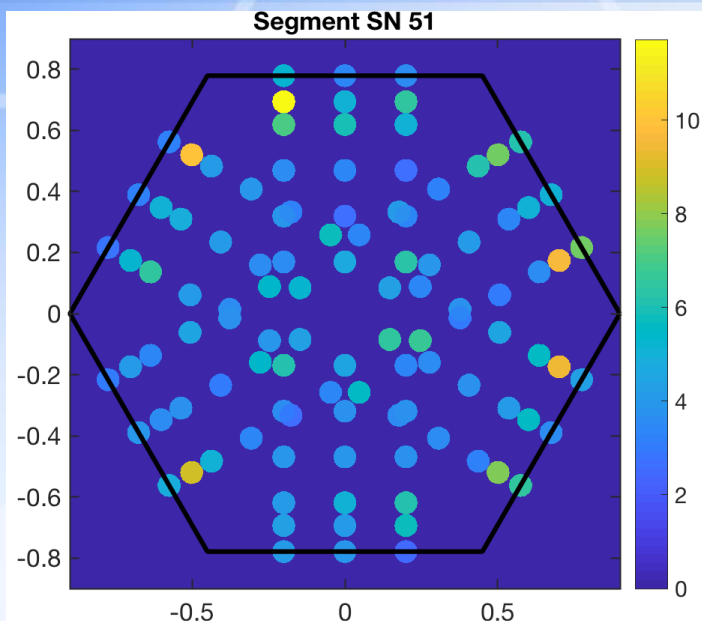
Scattered Light From Edges

A Systematic Evaluation



- 25% of segments have edges with a significant reduction ($> 20\%$) in intensity within ± 3.5 arcseconds

Preliminary Results From Measurements of Keck segments with an Interferometer



- ◆ The predicted TMT residual AO (120CL) M1 surface errors are 6nm RMS surface
- ◆ The proposed TMT requirement for these spatial frequencies is 5 nm RMS surface
- ◆ Artifacts from IBF support pads are excluded from the RMS surface error calculations

- ◆ RMS surface errors over the 15 cm interferometric phase measurement

- ◇ Zernike orders 1 and 2 removed

Segment Edge Summary

- ◆ Stress Mirror Polishing (SMP) was designed to NOT introduce edge effects
 - ◇ Ion Beam Polishing (IBF) post SMP however, can introduce edge effects at these 1-3 cm spatial frequencies
- ◆ Other mirror polishing techniques such as those used for segments for space telescopes will also likely introduce edge effects
- ◆ If the TMT segments are similar to the Keck segments it would reduce the H-band Strehl by $\sim 5\%$ and have a significant impact on contrast